REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
24-10-2005	Briefing Charts	

4. TITLE AND SUBTITLE

Ionic Liquids R&D at US Air Force Research Laboratory (Preprint)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER
5026

5e. TASK NUMBER
0541

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory (AFMC)
AFRL/PRSP
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8. PERFORMING ORGANIZATION REPORT NUMBER

AFRL-PR-ED-VG-2005-397

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory (AFMC)
AFRL/PRS
5 Pollux Drive
Edwards AFB CA 93524-70448

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S NUMBER(S)
AFRL-PR-ED-VG-2005-397

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Presented at Partners in Environmental Technology – Technology Symposium, Washington, DC, 01 Dec 2005.

14. ABSTRACT
N/A

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Dr. Tommy W. Hawkins
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
Unclassified	**Unclassified**	**Unclassified**	A	9	(661) 275-5449

Ionic Liquids R&D at US Air Force Research Laboratory (PREPRINT)

USAF AFRL

Edwards AFB CA

Issues and Drivers

- **Increased Testing and Operations Costs:**
  - System Handling/Fueling
  - Monitoring System in Field
  - Delays in Launch for Corridor
    - **Hazardous/Carcinogenic Vapor (Respiratory Route)**
    - **Dermal Toxicity**

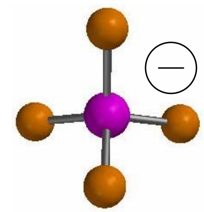
- **Performance of SOTA Propellant**
  - Desire Improved Isp and D*Isp
    - **Improved Capabilities (Payload and Range)**

System Handling/Fueling

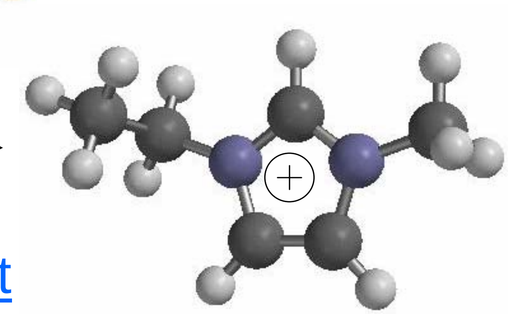
Energetic Ionic Liquids

- **Background**
  - An ionic compound that has a melting point at or below 100ºC
  - Seminal work at USAFA
  - Industrial solvents, green chemistry
  - Ionic Liquids current focus area of AFOSR

  AFRL now leading energetic IL discovery/development



$AlCl_4^-$



EMIM cation

- **Advantages as Energetic Materials**
  - Low vapor pressure, **low vapor toxicity**
  - High density
  - Physical and chemical properties can be tailored

Can adjust these properties by:
- **Varying cation and anion**
  - **Size, shape, symmetry, composition, hydrogen bonding**
- **Creating mixtures, eutectics, etc.**

Why ILs as Energetic Materials?

<u>"Tuning" IL structure for</u>:
Energy content
Oxygen balance
Melting point
Liquid range

<u>Propulsion</u>:
Thrusters

<u>Explosives</u>:
Melt-cast munitions

<u>Power Plants</u>
Power generators, APUs,….

AFRL Ionic Liquids

Why Ionic Liquids for Propulsion?

- A figure of merit (FOM) can be based on the momentum imparted by a HEDM normalized by that of a standard material (e.g., NTO/MMH)
- Two main properties
  1) Average kinetic energy (KE) of gases produced per unit mass of HEDM combusted/decomposed
  2) Density (ρ) of material

$$FOM = [(2KE_{HEDM})^{1/2} \ln(1 + c'\rho_{HEDM})] / [(2KE_{STAND})^{1/2} \ln(1 + c'\rho_{STAND})]$$

(where, c' = Material volume/Mass of combustor; and set to 1.0 m^3/kg)

KE ↑

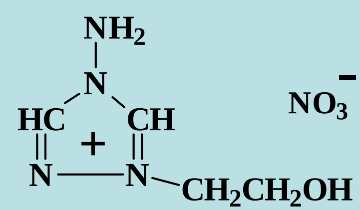
Tc ↑

ΔHf ↑

	NTO-HEHN	NTO-HEATN	NTO-MMH
KE (MJ/kg)	3.9	4.0	4.7
ρ (kg/m^3)	1424	1454	1189
FOM (STAND=NTO/MMH)	1.03	1.05	1.0

$[HOCH_2CH_2N_2H_4]^+ \; NO_3^-$

HEHN; ρ= 1.42 g/cc; MP <-25C



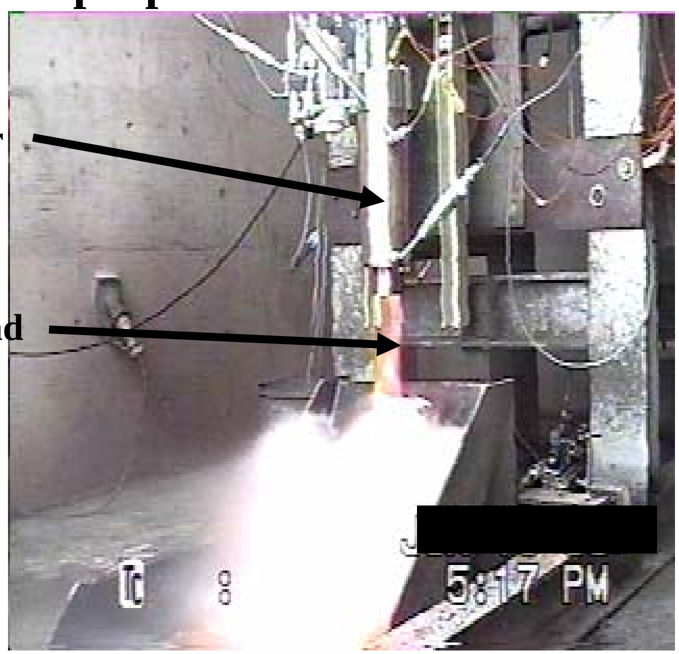
HEATN; ρ= 1.48 g/cc; MP = 0C

Ionic Liquid Fuel for Bipropulsion

Goal: Demonstrate feasibility of ionic liquid as fuel for bipropellant systems

Accomplishment

- AFRL/PRSP working with Purdue University has successfully tested high performance ionic liquid fuel in a bipropellant thruster

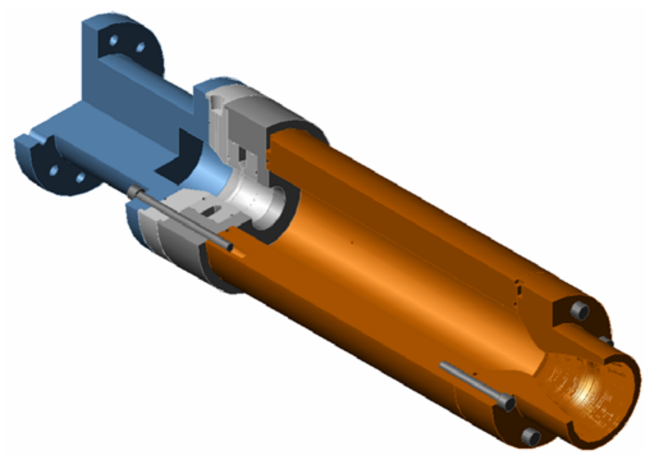


Thruster during bipropellant operation (93% C* efficiency)

Significance

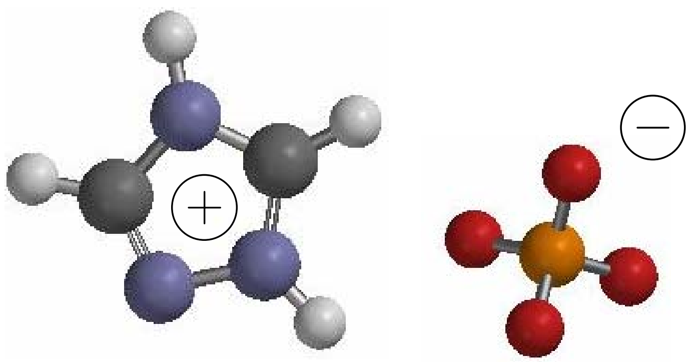
- Storable bipropellant system with potential increase in performance over NTO/MMH
- Greatly reduced toxicity vs NTO/MMH
  - Using ionic liquid instead of MMH
  - Using hydrogen peroxide instead of NTO

Staged bipropellant thruster for ionic liquid fuel

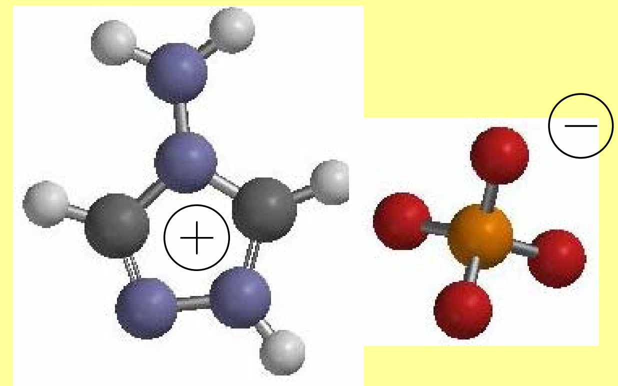


Ionic Liquids in Munitions

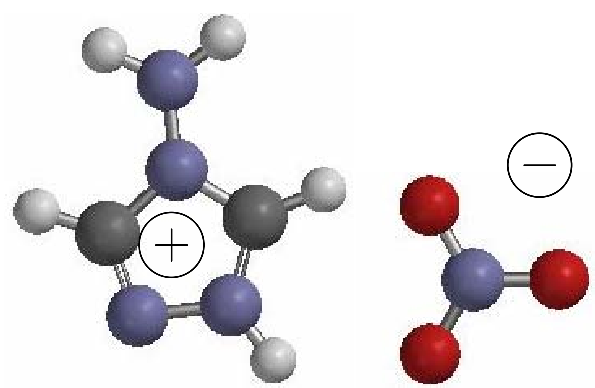
- Triazolium salts initially synthesized at USAF
- Scaled to the 50 gram level and characterized in ONR program



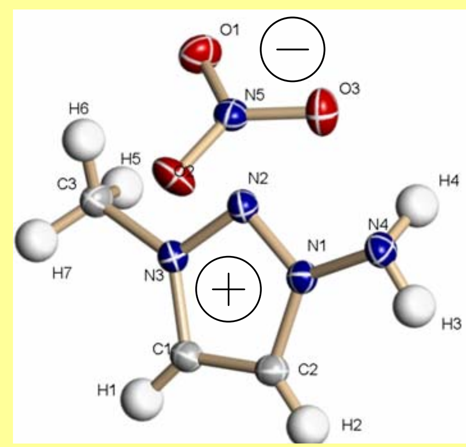
1,2,4-triazolium perchlorate



4-amino-1,2,4-triazolium perchlorate (4-ATP)



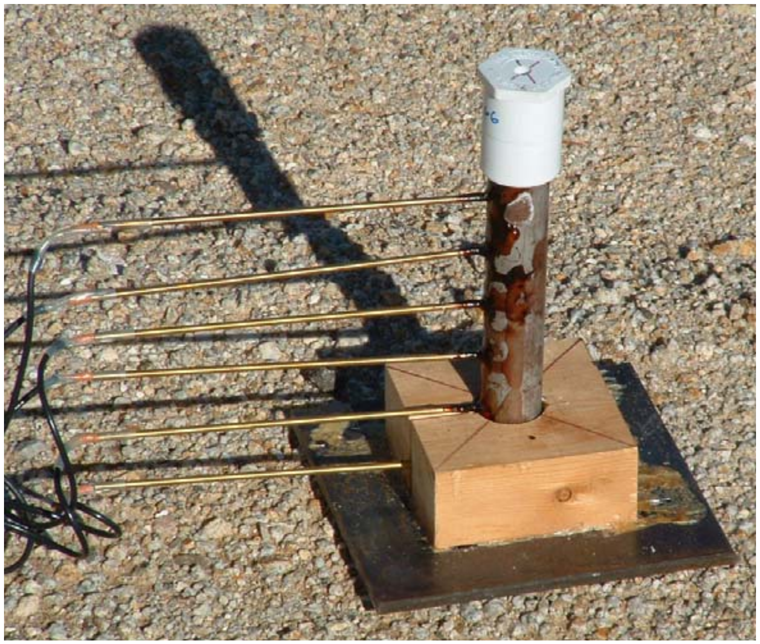
4-amino-1,2,4-triazolium nitrate



1-amino-3-methyl-1,2,3-triazolium nitrate

Energetic Ionic Liquids for TNT replacements

Very promising initial results!!



Shock velocity determination

- **4-ATP (melt cast) ρ = 1.74 g/cm^3; shock velocity = 8.3 mm/usec**
- **TNT (pressed) ρ = 1.63 g/cm^3; shock velocity = 6.9 mm/usec (LLNL Data)**

4-ATP is approaching energy output of high melt point, state-of-the-art nitramines like RDX !